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Reverse of Bebiano-Lemos-Providência inequality and Complementary Furuta inequality

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We give a simultaneous extension of Bebiano-Lemos-Providência inequality and Araki-Cordes one: Let A and B be positive operators. Then for each $r \geq 0$

$$\|A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}}\| \leq \|A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{s}} A^{\frac{r}{2}}\| \quad \text{for } s \geq t \geq 0.$$

In succession, we prove a reverse inequality: Let A and B be positive operators. Then for each $r \geq 0$

$$\|A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}}\| \geq \|A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{s}} A^{\frac{r}{2}}\| \quad \text{for } t \geq s \geq r \geq 0.$$

Furthermore, we discuss reverse of generalized BLP inequality in a general setting, in which we point out that the restriction $t \geq s \geq r$ in the above is quite reasonable.

1 Introduction

Let A be a bounded linear operator acting on a Hilbert space H . Then A is positive, denoted by $A \geq 0$, if $(Ax, x) \geq 0$ for all $x \in H$. In particular, $A > 0$ means that A is invertible and positive.

Recently, Bebiano-Lemos-Providência showed an interesting norm inequality (BLP): Let A and B be positive operators. Then

$$(1) \quad \|A^{\frac{1+t}{2}} B^t A^{\frac{1+t}{2}}\| \leq \|A^{\frac{1}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{s}} A^{\frac{1}{2}}\| \quad \text{for } s \geq t \geq 0.$$

If we delete $A^{\frac{1}{2}}$ on both sides in (1), we have the Araki-Cordes inequality (AC)

$$(2) \quad \|A^p B^p A^p\| \leq \|ABA\|^p \quad \text{for } 0 \leq p \leq 1.$$

In this sense, BLP inequality (1) is regarded as an extension of AC inequality (2).

In this note, we first give a simultaneous extension of (1) and (2) as follows generalized BLP inequality (GBLP): Let A and B be positive operators. Then for each $r \geq 0$

$$(3) \quad \|A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}}\| \leq \|A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{s}} A^{\frac{r}{2}}\| \quad \text{for } s \geq t \geq 0.$$

Next we discuss a reverse inequality of (3) (R-GBLP): Let A and B be positive operators. Then for each $r \geq 0$,

$$(4) \quad \|A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}}\| \geq \|A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{s}} A^{\frac{r}{2}}\| \quad \text{for } t \geq s \geq r \text{ and } s > 0.$$

As a corollary, the case $r = 1$ in (4) corresponds to the reverse of BLP(R-BLP) inequality and the case $r = 0$ in (4) corresponds to the reverse of AC inequality (2)(R-AC).

2 A generalization of BLP inequality

In this section, we generalize BLP inequality (1). For this, we cite Furuta inequality: Let $A \geq B$ for A and B be positive operators. Then for each $r \geq 0$.

$$(A^{\frac{r}{2}} B^p A^{\frac{r}{2}})^{\frac{1}{q}} \leq (A^{\frac{r}{2}} A^p A^{\frac{r}{2}})^{\frac{1}{q}} \quad \text{for } p \geq 0, \quad q \geq 1 \quad \text{with } (1+r)q \geq p+r.$$

We prove the following theorem including BLP inequality and AC one.

Theorem. 1. *Let A and B be positive operators. Then for each $r \geq 0$*

$$\| A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}} \| \leq \| A^{\frac{r}{2}} (A^{\frac{t}{2}} B^s A^{\frac{t}{2}})^{\frac{1}{s}} A^{\frac{r}{2}} \| \quad \text{for } s \geq t \geq 0.$$

Proof. Since this inequality is AC inequality when $r = 0$, we may assume $r > 0$. It suffices to prove that

$$A^{\frac{r}{2}} (A^{\frac{t}{2}} B^s A^{\frac{t}{2}})^{\frac{1}{s}} A^{\frac{r}{2}} \leq 1 \implies A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}} \leq 1 \quad \text{for } s \geq t \geq 0.$$

If $A^{\frac{r}{2}} (A^{\frac{t}{2}} B^s A^{\frac{t}{2}})^{\frac{1}{s}} A^{\frac{r}{2}} \leq 1$, then $(A^{\frac{t}{2}} B^s A^{\frac{t}{2}})^{\frac{1}{s}} \leq A^{-r}$. We put

$$A_1 = A^{-r}, \quad B_1 = (A^{\frac{t}{2}} B^s A^{\frac{t}{2}})^{\frac{1}{s}} \quad r_1 = \frac{s}{r} \quad \text{and} \quad p = q = \frac{s}{t}.$$

Then

$$A_1 \geq B_1 \geq 0, \quad r_1 \geq 0, \quad p = q \geq 1 \quad \text{and} \quad (1+r_1)q \geq p+r_1,$$

so that Furuta inequality implies

$$(A_1^{\frac{r_1}{2}} B_1^p A_1^{\frac{r_1}{2}})^{\frac{1}{q}} \leq (A_1^{\frac{r_1}{2}} A_1^p A_1^{\frac{r_1}{2}})^{\frac{1}{q}},$$

that is,

$$(A_1^{\frac{r_1}{2}} B_1^{\frac{t}{s}} A_1^{\frac{r_1}{2}})^{\frac{1}{s}} \leq (A_1^{\frac{r_1}{2}} A_1^{\frac{t}{s}} A_1^{\frac{r_1}{2}})^{\frac{1}{s}}.$$

Since we have

$$A = A_1^{-\frac{1}{r}}, \quad B = (A^{-\frac{t}{2}} B_1^{\frac{t}{s}} A^{-\frac{t}{2}})^{\frac{1}{s}} = (A_1^{\frac{r_1}{2}} B_1^{\frac{t}{s}} A_1^{\frac{r_1}{2}})^{\frac{1}{s}},$$

it follows that

$$\begin{aligned} A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}} &= (A_1^{-\frac{1}{r}})^{\frac{r+t}{2}} (A_1^{\frac{r_1}{2}} B_1^{\frac{t}{s}} A_1^{\frac{r_1}{2}})^{\frac{1}{s}} (A_1^{-\frac{1}{r}})^{\frac{r+t}{2}} \\ &\leq A_1^{-\frac{r+t}{2r}} (A_1^{-\frac{t}{2}} A_1^{\frac{t}{s}} A_1^{-\frac{t}{2}})^{\frac{1}{s}} A_1^{-\frac{r+t}{2r}} = A_1^{-\frac{r+t}{2r}} A_1^{\frac{r+t}{r}} A_1^{-\frac{r+t}{2r}} = I. \end{aligned}$$

□

Remark. It is obvious that the case $r = 1$ in Theorem 1 is just the BLP inequality and the case $r = 0$ is AC one.

3 Reverse inequalities

In this section, we show a reverse inequality of Theorem 1, in which we use the well-known formula (Lemma of Furuta),

$$(5) \quad (A^{\frac{1}{2}}BA^{\frac{1}{2}})^p = A^{\frac{1}{2}}B^{\frac{1}{2}}(B^{\frac{1}{2}}AB^{\frac{1}{2}})^{p-1}B^{\frac{1}{2}}A^{\frac{1}{2}} \quad \text{for } p \geq 1$$

and Löwner-Heinz inequality (LH)

$$(6) \quad A \geq B \geq 0 \quad \text{implies} \quad A^p \geq B^p \quad \text{for all } 0 \leq p \leq 1.$$

Theorem. 2. *Let A and B be positive operators. Then for each $r \geq 0$*

$$(7) \quad \|A^{\frac{r+t}{2}}B^tA^{\frac{r+t}{2}}\| \geq \|A^{\frac{r}{2}}(A^{\frac{1}{2}}B^sA^{\frac{1}{2}})^{\frac{t}{s}}A^{\frac{r}{2}}\| \quad \text{for } t \geq s \geq r \quad \text{and } s > 0.$$

Proof. It suffices to prove that

$$A^{\frac{r+t}{2}}B^tA^{\frac{r+t}{2}} \leq 1 \implies A^{\frac{r}{2}}(A^{\frac{1}{2}}B^sA^{\frac{1}{2}})^{\frac{t}{s}}A^{\frac{r}{2}} \leq 1 \quad \text{for } t \geq s \geq r \quad \text{and } s > 0.$$

Suppose that $\lfloor \frac{t}{s} \rfloor = 2l - 1$ or $2l$ for some natural number l . Then following equations are obtained by (5).

$$\begin{aligned} & A^{\frac{r}{2}}(A^{\frac{1}{2}}B^sA^{\frac{1}{2}})^{\frac{t}{s}}A^{\frac{r}{2}} \\ &= A^{\frac{r+t}{2}}B^{\frac{t}{s}}(B^{\frac{1}{2}}A^sB^{\frac{1}{2}})^{\frac{t}{s}-1}B^{\frac{1}{2}}A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}}B^sA^{\frac{r}{2}}(A^{\frac{1}{2}}B^sA^{\frac{1}{2}})^{\frac{t}{s}-2}A^{\frac{1}{2}}B^sA^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}}(B^sA^s)B^{\frac{t}{s}}(B^{\frac{1}{2}}A^sB^{\frac{1}{2}})^{\frac{t}{s}-3}B^{\frac{1}{2}}(A^sB^s)A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}}(B^sA^s)B^sA^{\frac{r}{2}}(A^{\frac{1}{2}}B^sA^{\frac{1}{2}})^{\frac{t}{s}-4}A^{\frac{1}{2}}B^s(A^sB^s)A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}}(B^sA^s)(B^sA^s)B^{\frac{t}{s}}(B^{\frac{1}{2}}A^sB^{\frac{1}{2}})^{\frac{t}{s}-5}B^{\frac{1}{2}}(A^sB^s)(A^sB^s)A^{\frac{r+t}{2}} \\ &\vdots \\ &= A^{\frac{r+t}{2}} \overbrace{(B^sA^s) \cdots (B^sA^s)}^{(l-1)\text{-times}} B^{\frac{t}{s}} (B^{\frac{1}{2}}A^sB^{\frac{1}{2}})^{\frac{t}{s}-(2l-1)} B^{\frac{1}{2}} \overbrace{(A^sB^s) \cdots (A^sB^s)}^{(l-1)\text{-times}} A^{\frac{r+t}{2}} \end{aligned}$$

Since $t \geq s \geq r \geq 0$, we have

$$0 \leq \frac{s}{r+t} \leq 1, \quad 0 \leq \frac{s}{t} \leq 1, \quad 0 \leq \frac{t(r+s) - 2(l-h)rs}{t(r+t)} \leq 1 \quad \text{for } h = 1, 2, \dots, l$$

and

$$0 \leq \frac{t(s-r) + 2(l-k)rs}{t(r+t)} \leq 1 \quad \text{for } k = 0, 1, \dots, l-1.$$

We suppose that $A^{\frac{r+t}{2}}B^tA^{\frac{r+t}{2}} \leq 1$, that is,

$$B^t \leq A^{-(r+t)} \quad \text{and} \quad A^{(r+t)} \leq B^{-t}.$$

So the Löwner-Heinz inequality (6) implies that

$$A^s \leq B^{-\frac{st}{r+t}}, \quad B^s \leq A^{-\frac{s(r+t)}{t}}, \quad B^{\frac{t(r+s)-2(l-h)rs}{(r+t)}} \leq A^{-\frac{t(r+s)-2(l-h)rs}{t}} \quad \text{for } h = 1, 2, \dots, l$$

and

$$A^{\frac{t(s-r)+2(l-k)rs}{t}} \leq B^{-\frac{t(s-r)+2(l-k)rs}{(r+t)}} \quad \text{for } k = 0, 1, \dots, l-1.$$

Now we assume that $\lfloor \frac{t}{s} \rfloor = 2l - 1$ for some natural number l . Since $0 \leq \frac{t}{s} - (2l - 1) \leq 1$, we have

$$\begin{aligned} & A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{2}} A^{\frac{r}{2}} \\ &= A^{\frac{r+t}{2}} \overbrace{(B^s A^s) \cdots (B^s A^s)(B^s A^s)}^{(l-1)\text{-times}} B^{\frac{s}{2}} (B^{\frac{s}{2}} A^s B^{\frac{s}{2}})^{\frac{t}{2} - (2l-1)} B^{\frac{s}{2}} \overbrace{(A^s B^s)(A^s B^s) \cdots (A^s B^s)}^{(l-1)\text{-times}} A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s)(B^s A^s) B^{\frac{s}{2}} (B^{\frac{s}{2}} B^{-\frac{st}{r+t}} B^{\frac{s}{2}})^{\frac{t}{2} - (2l-1)} B^{\frac{s}{2}} (A^s B^s)(A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s)(B^s A^s) B^{\frac{t(s+r)-2(l-1)rs}{r+t}} (A^s B^s)(A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}} \overbrace{(B^s A^s) \cdots (B^s A^s)}^{(l-2)\text{-times}} B^s A^s B^{\frac{t(s+r)-2(l-1)rs}{r+t}} A^s B^s \overbrace{(A^s B^s) \cdots (A^s B^s)}^{(l-2)\text{-times}} A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s) B^s A^{\frac{t(s-r)+2(l-1)rs}{t}} B^s (A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s) B^{\frac{t(s+r)-2(l-2)rs}{r+t}} (A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &\vdots \\ &\leq A^{\frac{r+t}{2}} B^s A^{\frac{t(s-r)+2(l-(l-1))rs}{t}} B^s A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} B^{\frac{ts+rt}{r+t}} A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} A^{-(r+s)} A^{\frac{r+t}{2}} \\ &= I. \end{aligned}$$

On the other hand, we assume that $\lfloor \frac{t}{s} \rfloor = 2l$ for some natural number l . Since $0 \leq \frac{t}{s} - 2l \leq 1$, similarly we have the following, in which the first equality is ensured in the first paragraph.

$$\begin{aligned} & A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{2}} A^{\frac{r}{2}} \\ &= A^{\frac{r+t}{2}} \overbrace{(B^s A^s) \cdots (B^s A^s)(B^s A^s)}^{(l-1)\text{-times}} B^{\frac{s}{2}} (B^{\frac{s}{2}} A^s B^{\frac{s}{2}})^{\frac{t}{2} - (2l-1)} B^{\frac{s}{2}} \overbrace{(A^s B^s)(A^s B^s) \cdots (A^s B^s)}^{(l-1)\text{-times}} A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}} \overbrace{(B^s A^s) \cdots (B^s A^s)(B^s A^s)}^{(l-1)\text{-times}} B^s A^{\frac{s}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{t}{2} - 2l} A^{\frac{s}{2}} B^s \overbrace{(A^s B^s)(A^s B^s) \cdots (A^s B^s)}^{(l-1)\text{-times}} A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s)(B^s A^s) B^s A^{\frac{s}{2}} (A^{\frac{s}{2}} A^{-\frac{s(r+t)}{t}} A^{\frac{s}{2}})^{\frac{t}{2} - 2l} A^{\frac{s}{2}} B^s (A^s B^s)(A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s)(B^s A^s) B^s A^{\frac{t(s-r)+2ls}{t}} B^s (A^s B^s)(A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &\leq A^{\frac{r+t}{2}} (B^s A^s) \cdots (B^s A^s)(B^s A^s) B^s B^{-\frac{t(s-r)+2lrs}{r+t}} B^s (A^s B^s)(A^s B^s) \cdots (A^s B^s) A^{\frac{r+t}{2}} \\ &= A^{\frac{r+t}{2}} \overbrace{(B^s A^s) \cdots (B^s A^s)}^{(l-2)\text{-times}} B^s A^s B^{\frac{t(r+s)-2(l-1)rs}{r+t}} A^s B^s \overbrace{(A^s B^s) \cdots (A^s B^s)}^{(l-2)\text{-times}} A^{\frac{r+t}{2}} \\ &\vdots \\ &\leq I. \end{aligned}$$

Hence the proof is complete. \square

4 Complementary Furuta inequality

In this section, we consider **R-GBLP**, in which Kamei's theorem(**Theorem K**) on complements of Furuta inequality corresponds to our result. So now recall it due to Kamei.

Theorem K. *If $A \geq B > 0$, then for $0 < p \leq \frac{1}{2}$*

$$(8) \quad A^t \natural_{\frac{2p-t}{p-t}} B^p \leq A^{2p} \quad \text{for } 0 \leq t \leq p$$

and for $\frac{1}{2} \leq p \leq 1$

$$(9) \quad A^t \natural_{\frac{1-t}{p-t}} B^p \leq A \quad \text{for } 0 \leq t \leq p.$$

Here \natural_q for $q \notin [0, 1]$ has been used as

$$A \natural_q B := A^{\frac{1}{2}} (A^{-\frac{1}{2}} B A^{-\frac{1}{2}})^q A^{\frac{1}{2}} \quad \text{for } A, B > 0.$$

First we prove the following Theorem.

Theorem. 3. *Let $A, B \geq 0$ and $0 < p \leq 1$. Then*

$$(10) \quad \| A^{\frac{1+s}{2}} B^{1+s} A^{\frac{1+s}{2}} \|_{\frac{p+s}{p(1+s)}}^{\frac{p+s}{p(1+s)}} \geq \| A^{\frac{1}{2}} (A^{\frac{s}{2}} B^{p+s} A^{\frac{s}{2}})^{\frac{1}{p}} A^{\frac{1}{2}} \|$$

for all $s \geq 0$ with $s \geq 1 - 2p$.

Proof. It suffices to show that

$$(11) \quad B^{1+s} \leq A^{-(1+s)} \Rightarrow A^{\frac{1}{2}} (A^{\frac{s}{2}} B^{p+s} A^{\frac{s}{2}})^{\frac{1}{p}} A^{\frac{1}{2}} \leq 1$$

for $0 < p \leq 1$ and $s \geq 0$ with $s \geq 1 - 2p$. So we put

$$A_1 = A^{-(1+s)}, \quad B_1 = B^{1+s}.$$

Then (11) is rephrased as

$$A_1 \geq B_1 > 0 \Rightarrow A_1^{\frac{1}{1+s}} \natural_{\frac{1}{p}} B_1^{\frac{p+s}{1+s}} \leq A_1.$$

for $0 < p \leq 1$ and $s \geq 0$ with $s \geq 1 - 2p$. Moreover if we replace

$$t_1 = \frac{s}{1+s}, \quad p_1 = \frac{p+s}{1+s},$$

then we have $\frac{1-t_1}{p_1-t_1} = \frac{1}{p}$, and $\frac{1}{2} \leq p_1 (\leq 1)$ if and only if $1 - 2p \leq s$, so that (11) has the following equivalent expression:

$$A_1 \geq B_1 > 0 \Rightarrow A_1^{t_1} \natural_{\frac{1-t_1}{p_1-t_1}} B_1^p \leq A_1 \quad \text{for } 0 \leq t_1 < p_1.$$

Fortunately, since $\frac{1}{2} \leq p_1 \leq 1$, it has been ensured by Theorem A due to Kamei. \square

Next we show a reverse inequality of BLP inequality (**R-BLP**) is obtained as colloary of Theorem 3.

Proof of R-BLP We put $p = \frac{s}{t}$ for $t \geq s \geq 0$. Then we have $1 - 2p \leq s$ if and only if $\frac{t}{t+2} \leq s$. Since $s \geq 1$ is assumed, $\frac{t}{t+2} \leq s$ holds for arbitrary $t > 0$, so that Theorem 3 is applicable.

Now we take $B_1 = B^{\frac{1+t}{t}}$, i.e., $B = B_1^{\frac{t}{1+t}}$. Then Araki-Cordes inequality and Theorem 3 imply that

$$\begin{aligned} \| A^{\frac{1+t}{2}} B_1^t A^{\frac{1+t}{2}} \| &\geq \| A^{\frac{1+s}{2}} B_1^{\frac{t(1+s)}{1+t}} A^{\frac{1+s}{2}} \| \frac{1+t}{1+s} = \| A^{\frac{1+s}{2}} B^{1+s} A^{\frac{1+s}{2}} \| \frac{2+s}{2(1+s)} \\ &\geq \| A^{\frac{1}{2}} (A^{\frac{s}{2}} B^{p+s} A^{\frac{s}{2}})^{\frac{1}{p}} A^{\frac{1}{2}} \| = \| A^{\frac{1}{2}} (A^{\frac{s}{2}} B_1^s A^{\frac{s}{2}})^{\frac{1}{p}} A^{\frac{1}{2}} \|, \end{aligned}$$

as desired.

R-BLP is generalized a bit as follows:

Corollary. For $A, B > 0$ and $r \geq 0$

$$(12) \quad \| A^{\frac{r+t}{2}} B^t A^{\frac{r+t}{2}} \| \geq \| A^{\frac{r}{2}} (A^{\frac{s}{2}} B^s A^{\frac{s}{2}})^{\frac{1}{p}} A^{\frac{r}{2}} \|$$

holds for all $t \geq s \geq r$.

Proof. It is proved by applying **R-BLP** to $A_1 = A^r$, $B_1 = B^r$ and $t_1 = \frac{t}{r}$, $s_1 = \frac{s}{r}$. \square

Finally we consider a reverse inequality of generalized BLP inequality which corresponds to another Kamei's complement (7): If $A \geq B > 0$, then for $0 < p \leq \frac{1}{2}$

$$A^t \natural_{\frac{2p-t}{p-t}} B^p \leq A^{2p} \quad \text{for } 0 \leq t < p.$$

Theorem. 4. Let $A, B \geq 0$ and $0 < p \leq \frac{1}{2}$. Then

$$(13) \quad \| A^{\frac{1+s}{2}} B^{1+s} A^{\frac{1+s}{2}} \| \frac{(2p+s)(p+s)}{p(1+s)} \geq \| A^{p+\frac{s}{2}} (A^{\frac{s}{2}} B^{p+s} A^{\frac{s}{2}})^{\frac{2p+s}{p}} A^{p+\frac{s}{2}} \|$$

for all $0 \leq s \leq 1 - 2p$.

Proof. A proof is quite similar to that of Theorem 3. We put

$$A_1 = A^{-(1+s)}, \quad B_1 = B^{1+s}; \quad t_1 = \frac{s}{1+s}, \quad p_1 = \frac{p+s}{1+s}.$$

Then (7) gives us that

$$A_1 \geq B_1 > 0 \Rightarrow A_1^{t_1} \natural_{\frac{2p_1-t_1}{p_1-t_1}} B_1^{p_1} \leq A_1^{2p_1},$$

for $0 \leq t_1 < p_1 \leq \frac{1}{2}$, so that

$$A^{-(1+s)} \geq B^{1+s} \Rightarrow A^{-s} \natural_{\frac{2p+s}{p}} B^{p+s} \leq A^{-2(p+s)}$$

for $0 \leq s \leq 1 - 2p$. Obviously it implies the desired norm inequality (12). \square

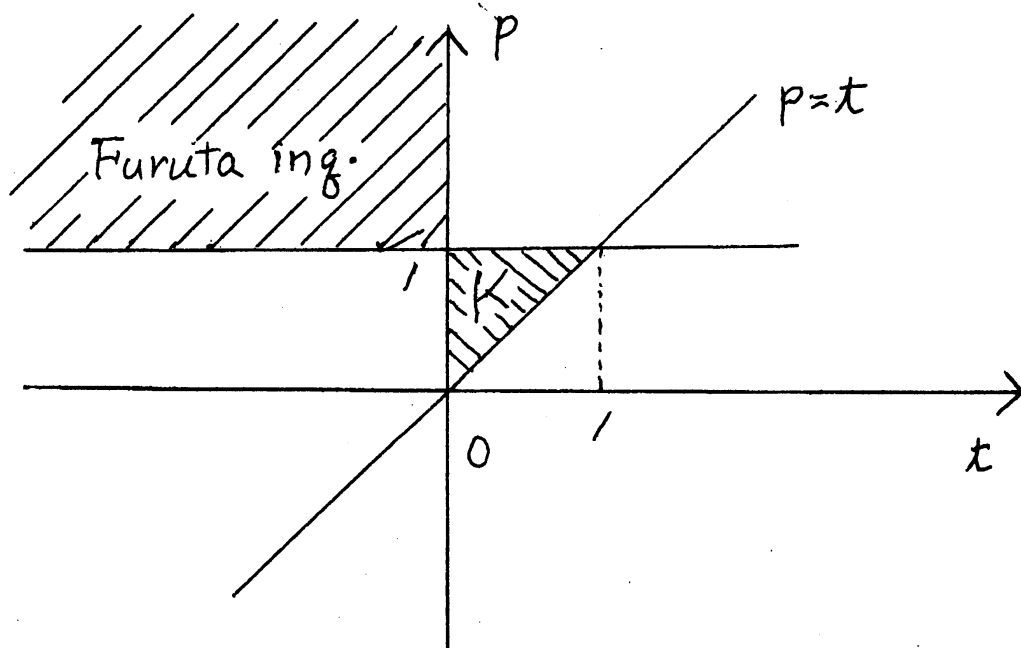
5 Remarks

We first consider a relation between Furuta inequality and Theorem K. Furuta inequality has the following representation by α -geometric mean \sharp_α : For $A \geq B \geq 0$

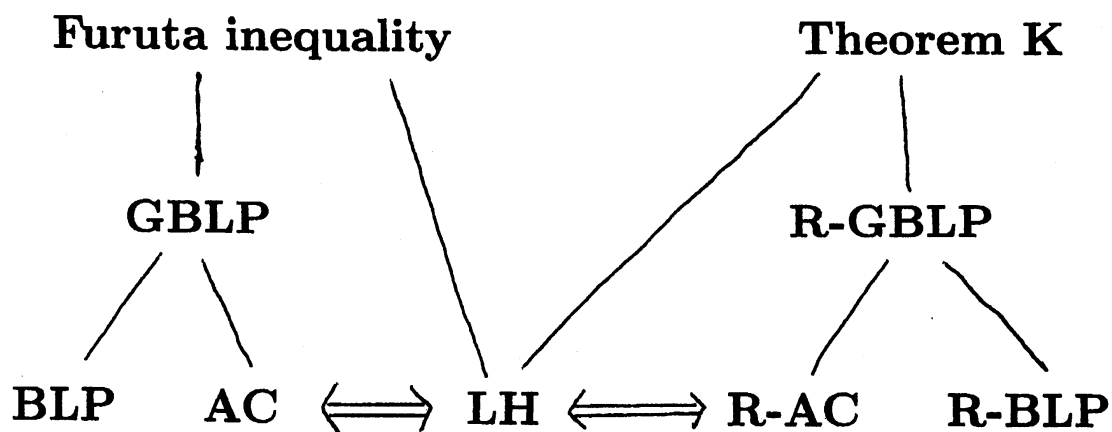
$$A^t \sharp_{\frac{1-t}{p-t}} B^p \leq A \quad \text{for } p \geq 1, t \leq 0$$

where $A \sharp_\alpha B$ for $0 \leq \alpha \leq 1$ is defined by

$$A \sharp_\alpha B := A^{\frac{1}{2}} (A^{-\frac{1}{2}} B A^{-\frac{1}{2}})^\alpha A^{\frac{1}{2}} \quad \text{for } A, B > 0.$$



As a consequence we have relations among the inequalities discussed above.



References

- [1] H. Araki, *On an inequality of Lieb and Thirring*, Lett. Math. Phys., **19**(1990), 167–170.
- [2] N. Bebiano, R. Lemos and J. Providência, *Inequalities for quantum relative entropy*, Linear Algebra Appl. **401**(2005), 159–172.
- [3] H.O. Cordes, *Spectral Theory of Linear Differential Operators and Comparison Algebras*, Cambridge University Press, 1987.
- [4] M. Fujii, *Furuta's inequality and its mean theoretic approach*, J. Operator theory, **23**(1990), 67–72.
- [5] M. Fujii, R. Nakamoto and M. Tominaga, *Generalized Bebiano-Lemos-Providência inequalities and their reverses*, Linear Algebra Appl., to appear.
- [6] T. Furuta, $A \geq B \geq 0$ assures $(B^r A^p B^r)^{1/q} \geq B^{(p+2r)/q}$ for $r \geq 0, p \geq 0, q \geq 1$ with $(1+2r)q \geq p+2r$, Proc. Amer. Math. Soc., **101**(1987), 85–88.
- [7] T. Furuta, *Elementary proof of an order preserving inequality*, Proc. Japan Acad., **65**(1989), 126.
- [8] T. Furuta, J. Mićić, J.E. Pečarić and Y. Seo, *Mond-Pečarić Method in Operator Inequalities*, Monographs in Inequalities 1, Element, Zagreb, 2005.
- [9] E. Kamei, *A satellite to Furuta's inequality*, Math. Japon., **33**(1988), 883–886.
- [10] E. Kamei, *Complements to Furuta inequality, II*, Math. Japon., **45**(1997), 15–23.
- [11] A. Matsumoto and R. Nakamoto, *Reverse of Bebiano-Lemos-Providência inequality*, preprint.
- [12] A. Matsumoto and M. Fujii, *Generalizations of reverse of Bebiano-Lemos-Providência inequality*, preprint.
- [13] G.K. Pedersen, *Some operator monotone functions*, Proc. Amer. Math. Soc., **36**(1972), 309–310.
- [14] K. Tanahashi, *Best possibility of the Furuta inequality*, Proc. Amer. Math. Soc., **124**(1996), 141–146.